

Radiation Biology and Radiation Therapy

Radiation Biology

- Radiation biology is a multidisciplinary field essential combining principles from **physics**, **chemistry**, and **biology** to **explain how radiation interacts with living organisms**.
- This knowledge is crucial for comprehending the **mechanisms** behind radiation therapy, **managing** its side effects, and **appreciating** the risks associated with radiation exposure.
- This lecture will break down these complex interactions into easily digestible concepts, focusing on the **types of radiation, their effects on biological tissues, their therapeutic applications, and their potential to induce cancer**.

Radiation Therapy

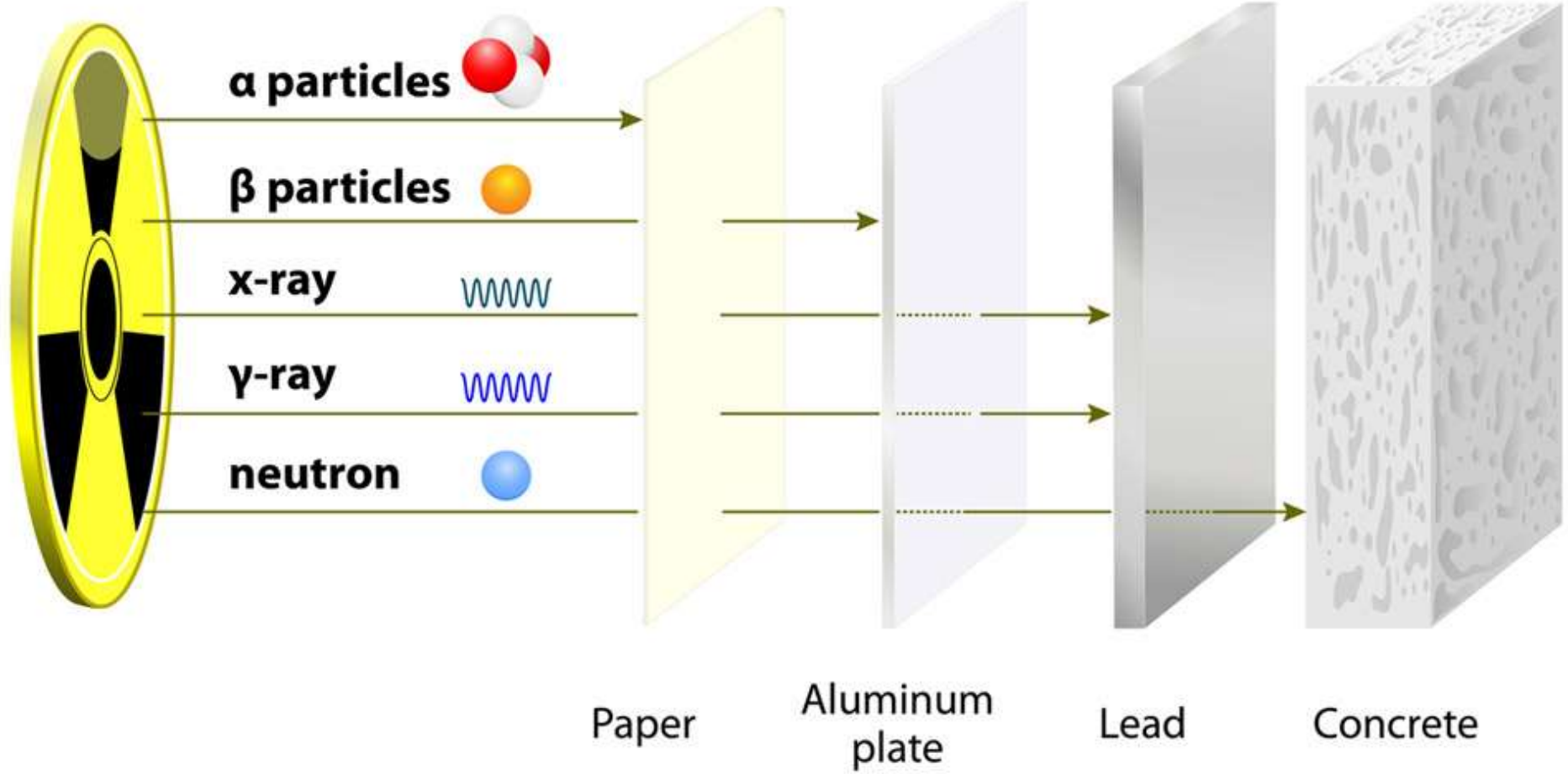
- **Radiation therapy** is a cornerstone in cancer treatment, leveraging its ability to damage cancerous cells, it also carries the inherent risk of damaging healthy tissues and potentially inducing secondary cancers.
- Modern radiation oncology accurately fits radiation delivery to **maximize** damage to tumors while **minimizing** exposure to surrounding healthy organs and manage patient side effects effectively.
- The **fundamental principle** that radiation interacts with biological tissues at the atomic and molecular level, primarily through ionization, leading to DNA damage and various cellular responses.

Radiation Types

- **Radiation**, broadly defined, is the emission or transmission of energy in the form of **waves** or **particles** through space or a material medium.
- For biological systems, the most relevant types are those capable of causing **ionization**.
- It's important to differentiate between **non-ionizing** and **ionizing** radiation.
- **Non-ionizing** radiation, like radio waves, microwaves, infrared, and visible light, has insufficient energy to remove electrons from atoms. While it can cause heating, it generally does not directly damage DNA.
- In contrast, **ionizing** radiation possesses enough energy to **knock electrons out of atoms**, creating charged particles (ions). This ionization is the primary mechanism through which radiation damages biological tissues.

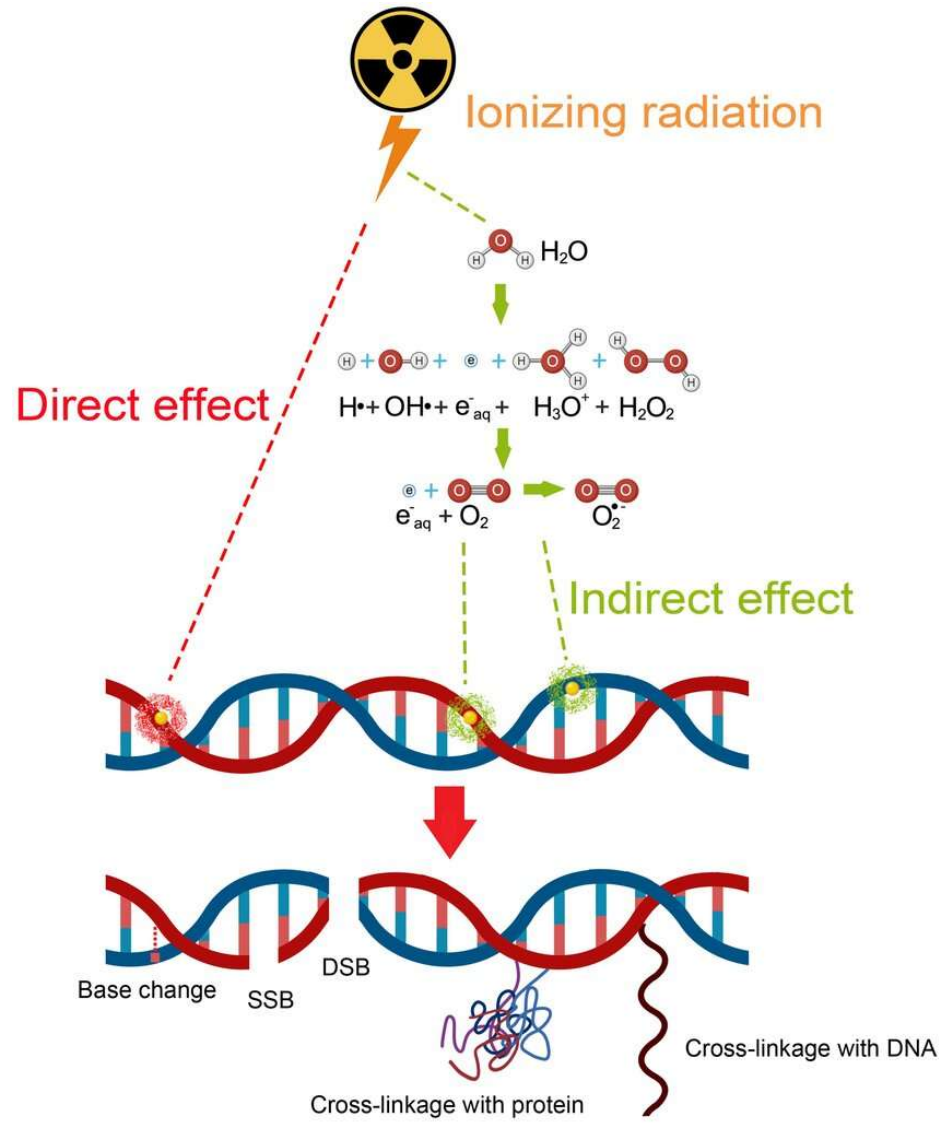
Key Types of Ionizing Radiation

- **Alpha Particles:** These are heavy particles consisting of two protons and two neutrons (**essentially a helium nucleus**). They are highly ionizing but have a very short range and are easily stopped by a sheet of paper or the outer layer of skin. However, if alpha-emitting isotopes are **ingested or inhaled**, they can cause significant localized damage to sensitive living tissue.
- **Beta Particles:** These are electrons with a range of energies. They are less ionizing and more penetrating than alpha particles, capable of penetrating a few millimeters into tissue.
- **Gamma Rays:** These are electromagnetic radiation, similar to X-rays but originating from the nucleus of an atom during radioactive decay. They are highly penetrating and can pass through several centimeters of tissue.
- **X-rays:** Also, a form of electromagnetic radiation, X-rays are produced outside the nucleus, typically by machines. Like gamma rays, they are highly penetrating and widely used in medical imaging and therapy.
- **Neutrons and Protons:** These are particulate radiations used in specialized radiation therapies. Neutrons are uncharged and can be highly damaging, while protons are positively charged and offer precise dose delivery due to their Bragg peak effect.



How Radiation Interacts with Biological Tissues

- The interaction of radiation with biological tissues is a **complex cascade of physical, chemical, and biological** events that ultimately lead to cellular damage.
- The Primary Interaction: **ionization and Free Radical Formation**
- When ionizing radiation passes through tissue, it interacts with atoms and molecules within the cells. This interaction can occur in two main ways:
 - **Direct Action:** The radiation directly strikes and ionizes critical biomolecules, most notably DNA, leading to immediate damage. This is more common with **high LET** (Linear Energy Transfer) radiations like **alpha particles**, which deposit a large amount of energy over a short distance.
 - **Indirect Action:** This is the predominant mechanism for sparsely ionizing radiation like **X-rays** and **gamma rays**. The radiation interacts with water molecules (which constitute about 80% of a cell), leading to the **radiolysis of water**. This process generates highly reactive species **called free radicals** (e.g., hydroxyl radicals, hydrated electrons). These free radicals then diffuse and chemically react with critical biomolecules, particularly DNA, causing damage.
- Regardless of direct or indirect action, the primary target and most critical structure for biological damage is **DNA**. Damage to DNA can manifest as **single-strand breaks SSB**, **double-strand breaks DSB**, **base damage**, or **cross-linking**. Double-strand breaks are considered the most lethal form of DNA damage as they are harder for the cell to repair accurately.



Cellular Responses to Radiation Damage

- Cells have evolved sophisticated mechanisms to detect and repair DNA damage. However, if the damage is too extensive or incorrectly repaired, several consequences can arise:
- **Cell Death:** Irreparable DNA damage can trigger programmed cell death (apoptosis) or mitotic catastrophe (cell death during an attempted division).
- **Mutation:** Incorrect repair of DNA damage can lead to permanent changes in the genetic code, resulting in mutations. These mutations can be harmless, harmful, or, in rare cases, contribute to carcinogenesis.
- **Chromosomal Aberrations:** Extensive damage can lead to visible changes in chromosome structure, such as translocations, deletions, or inversions.
- **Bystander Effects:** Interestingly, cells not directly hit by radiation can also exhibit biological responses, influenced by signals from irradiated neighboring cells. This "bystander effect" suggests a broader impact than just direct energy deposition.
- The biological effects on the whole body from radiation exposure depend on **several factors**, including the type and energy of the radiation, the absorbed dose, the dose rate, the area of the body exposed, and the sensitivity of the exposed tissue.

Principles of Radiation Therapy

- Despite its damaging potential, ionizing radiation is a powerful tool in medicine, primarily for treating cancer.
- Radiation therapy (**radiotherapy**) aims to deliver a precise, high dose of radiation to cancerous cells while minimizing exposure to surrounding healthy tissues.
- The effectiveness of radiation therapy stems from the differential radiosensitivity between cancer cells and healthy cells.
- Cancer cells often have **weakened DNA repair mechanisms** and are **typically rapidly dividing**, making them more susceptible to radiation-induced damage and cell death compared to healthy cells.

Key Techniques in Radiation Therapy

- **External Beam Radiation Therapy (EBRT):** This is the most common type, where radiation is delivered from a machine outside the body. Modern techniques allow for highly conformal and precise delivery.
- **Brachytherapy (Internal Radiation Therapy):** Involves placing radioactive sources directly into or very close to the tumor. This delivers a high dose to the tumor while rapidly decreasing the dose to surrounding healthy tissues. It can be temporary or permanent.
- **Systemic Radiation Therapy (Radiopharmaceuticals):** Involves administering radioactive substances (radiopharmaceuticals) that travel through the bloodstream to target cancer cells throughout the body. Examples include radioactive iodine for thyroid cancer or targeted radionuclide therapies that link a radioisotope to a molecule that specifically binds to cancer cells.

Pharmacist's Role in Radiation Therapy

- Pharmacists play a vital role in radiation therapy by managing side effects. Common side effects can include fatigue, hair loss, skin changes, nausea, vomiting, and specific symptoms depending on the irradiated area (e.g., dry mouth for head and neck radiation). Pharmacists can help with:
 - **Symptom Management:** Recommending and dispensing medications for pain, nausea, skin irritation, and other treatment-related symptoms.
 - **Patient Education:** Advising patients on proper skin care, nutritional support, and lifestyle modifications to mitigate side effects.
 - **Drug Interactions:** Identifying potential interactions between prescribed medications and those used to manage radiation side effects.
 - **Radiopharmaceutical Handling:** In certain specialized roles, pharmacists may be involved in the preparation and dispensing of radiopharmaceuticals, ensuring safety and compliance.